Isotropic and Deviatoric Moment Inversion of Regional Surface Waves from Nevada Test Site Explosions: Implications for Yield Estimation and Seismic Discrimination

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ABSTRACT:

Seismic moments of Nevada Test Site (NTS) explosions were determined from regional surface wave spectra. Two methods were used. In one the moment is solved for assuming only an explosive source, or average scalar moment; in the other a joint inversion for an isotropic (explosive) source plus a constrained double couple moment component representing tectonic strain release (TSR). Although the general moment tensor solution to this joint inversion problem is non-unique, if some assumptions are made concerning the non-isotropic moment components, then the remaining source parameters can be solved by a linear least-squares inversion scheme. We examined the errors in determining the isotropic moment component (M_I) by this latter method of constrained linear inversion solutions in a canonical study using a theoretical network of long-period (6-60 sec.) surface wave data. The network azimuthal coverage was chosen to represent that of a long-period North American super-network of 55 stations used for the actual NTS events. We compared these errors in moment estimate to those obtained from surface wave magnitude (M_S) and spectral scalar moment (M_0) measurements for the same surface wave observations. For a ratio of $M_{(expl)}/M_{(eq)}$ less than 1.0 we found that the inverted M_I solution is a much better estimate of the actual isotropic moment than either M_S or M_0, and the standard deviation in this estimate is substantially less than that using the other two methods for the great majority of isotropic source + double couple sources. Even when the inversion constraints are off in dip and rake each by 30^o, the mis-estimate of the isotropic moment is less than 35 percent of the actual value. In the case of a vertical strike-slip fault, the inverted isotropic moment solution which assumes this fault orientation is exact to three figures, whereas M_S and M_0 under-estimate the moment by 45 percent and 32 percent, respectively because of uneven azimuthal coverage.

This moment tensor inversion method was applied to determine the isotropic source for 111 NTS underground explosions using vertical and tangential component surface wave data from this regional network. We also calculated M_S and M_0 for these same events and compared the results. Isotropic source errors were smallest using the spectral domain inversion method. However, this spectral domain method cannot attain as low a magnitude threshold as the time domain moment or M_S method. The extensive moment data set analyzed were combined with larger yield explosions from prior moment studies to create a comprehensive data set with which to obtain conclusive, well-constrained long-period explosion source scaling relationships at the separate NTS sub-sites.

Regressing on the results presented here and the results of others for larger events with published yields, we obtained a M_I versus yield relation with which we were to estimate the surface wave inferred yields of the 111 NTS events.

Key Words Rayleigh and Love wave seismic moments, yields, NTS

OBJECTIVE:

To develop regional surface wave techniques for estimating seismic yield and to use these techniques to obtain a set of surface wave magnitudes, moments and inferred yields in as diverse an environment as possible at NTS in terms of yield, source location and shot medium. To relate the observed variations over NTS with known site characteristics inorder to transport or modify the relations for future test regions.

RECENT RESEARCH RESULTS:

The abstract summarises the results previously obtained under this grant which have been published in various reports and thesis. Here we present in tabular form our best estimates of the surface wave determined moments for 111 NTS events. Using published yields and the results of others for larger yields, we obtain a formula for log moment versus log yield. The figure shows the 6 fixed slope regressions based on subsets of the extended yield moment data set. The values of Given and Mellman (1986) were adjusted to correspond to the same shot point properties as used by us. The shot point independent values of Stevens (1985) were converted to our assumed source region velocity ratios. The order of the author names in the regression titles indicate that the first authors values were used instead of the other authors values if there was a discrepancy. It is interesting that the overlapping values of Given and Mellman were in agreement with Stevens eventhough Stevens used an azimuthally averaged value and Given and Mellman used a moment tensor inversion for the isotropic or explosion moment as in our analysis. In order to estimate yield, we used the regression formula determined from supplementing our values with those of Given and Mellman. The second sub-figure uses Stevens Piledriver value instead of ours and replaces our values by those of Given and Mellman when in conflict with ours. The difference in the regression constants is only 0.02. The regression formula is

$$\log M_I = LogY + 13.78$$

and was used to obtain the estimated yield Y_{SW} in the table.

Combining this log moment versus log yield relation with previous deteremined M_S versus log moment formulas, we obtain

$$M_S = \log Y + 2.34$$

or

$$M_S = \log Y + 1.91$$

depending on whether one uses regression formulas based on the Woods and Harkrider (1995) M_S magnitude values or those of Marshall *etal.* (1979). It shoulds noted that the latter formula is close to the commonly assumed formula for source regions of unknown geologic and seismic properties.

CONCLUSIONS AND RECOMMENSATIONS:

Until further NTS yields are published by the Department of Energy, especially below 10 kt, this set of surface wave estimated yields are about as good as one can accomplish from surface wave data and published yields at NTS. The moments are useful in testing ones ability to form and transport regional surface wave based discriminants and yield determination to other sites. These moments should not be considered as different from surface wave magnitudes but as more accurate and reliable

magnitudes. Their conversion formula to M_S has been presented in reports sponsored by this AFOSR grant.

References

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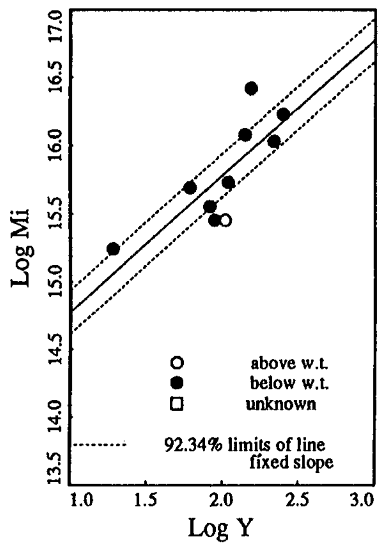
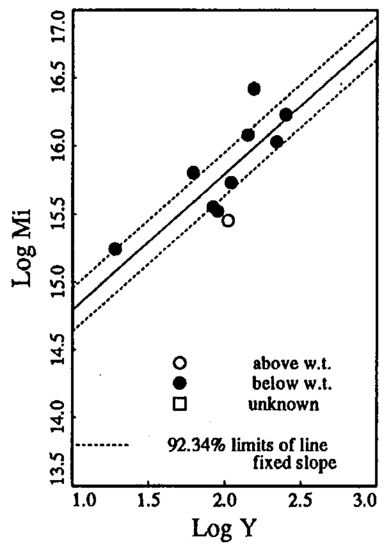
Woods&Harkrider+Given&Mellman, NTS



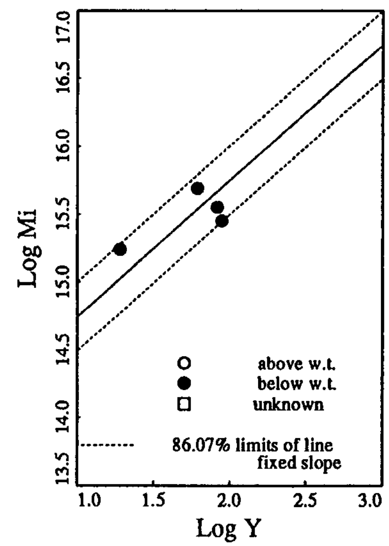
Log Mi =1.00 x Log Y +13.78
(s.d.=0.24)

Given&Mellman+Stevens+Woods&Harkrider, NTS



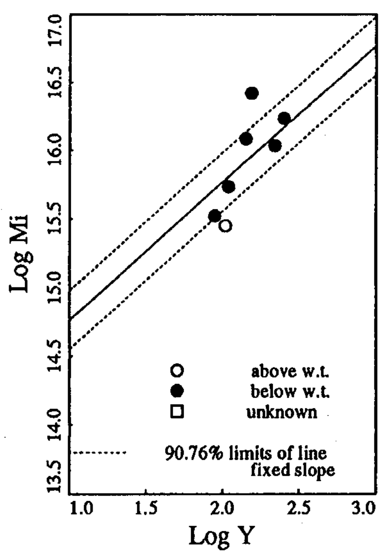
Log Mi =1.00 x Log Y +13.80
(s.d.=0.24)

Woods&Harkrider, NTS



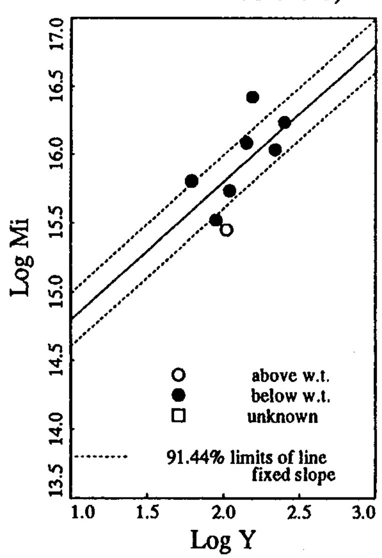
Log Mi =1.00 x Log Y +13.75
(s.d.=0.22)

Given&Mellman, NTS



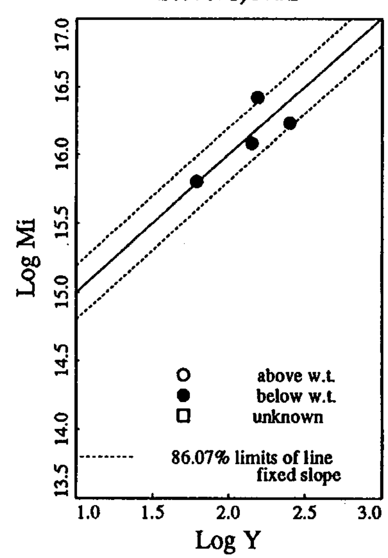
Log Mi =1.00 x Log Y +13.77
(s.d.=0.26)

Given&Mellman+Stevens, NTS



Log Mi =1.00 x Log Y +13.80
(s.d.=0.26)

Stevens, NTS



Log Mi =1.00 x Log Y +14.00
(s.d.=0.17)

Table (a): Best log moments and inferred yields								
NAME	Date	M_0	σ	$M_{I(R)}$	σ	$M_{I(R+L)}$	σ	Y_{SW}
WAGTAIL	65062	15.25	0.03	15.35	0.02	15.35	0.02	37
LAMPBLACK	66018	15.24	0.02	15.22	0.02	15.22	0.01	28
REX	66055	14.98	0.03	15.24	0.01	15.25	0.02	29
PIRANHA	66133	15.77	0.04	15.75	0.04	15.74	0.04	98
PILEDRIVER	66153	15.63	0.06	15.69	0.05	15.58	0.12	81
TAN	66154	15.74	0.04	15.73	0.04	15.72	0.04	91
MIDIMIST	67177	14.84	0.01	14.80	0.01	14.39	0.01	11
DOORMIST	67243	14.47	0.12					5
COBBLER	67312	15.05	0.01	14.98	0.02	14.94	0.02	19
DORSALFIN	68060	14.81	0.01	14.86	0.01			12
HUDSONSEAL	68268	14.84	0.01	14.81	0.01			11
WINESKIN	69015	15.41	0.02	15.47	0.05	15.46	0.07	43
CYPRESS	69043	14.65						7
BLENTON	69120	15.50	0.02	15.48	0.03	15.47	0.03	52
DIANAMIST	70042	14.77	0.05					10
SHAPER	70082	15.73	0.06	15.76	0.06	15.75	0.05	93
MINTLEAF	70125	14.93	0.01	16.85	0.01	14.59	0.01	14
HUDSONMOON	70146	14.55	0.01					6
CAMPHOR	71180	14.46	0.01	14.56	0.01			6
MINIATA	71189	15.55	0.02	15.59	0.03	15.54	0.03	59
ALGODONES	71230	15.15	0.01	15.14	0.01	15.11	0.01	23
MISTYNORTH	72123	14.65	0.01	14.85	0.01	14.82	0.01	12
MONERO	72140	14.76	0.01	14.78	0.01	14.76	0.01	10
DIAMONDSCULLS	72202	14.68	0.01	14.68	0.01			8
MIERA	73067	15.51	0.02	15.53	0.04	15.44	0.03	54
STARWORT	73116	15.45	0.03	15.46	0.04	15.46	0.04	47
DIDOQUEEN	73156	14.80	0.01	14.76	0.01			10
LATIR	74058	15.78	0.05	15.74	0.04	15.73	0.04	89

Table (b): Best log moments and inferred yields								
NAME	Date	M_0	σ	$M_{I(R)}$	σ	$M_{I(R+L)}$	σ	Y_{SW}
MINGBLADE	74170	14.84	0.01	14.88	0.01	14.92	0.01	14
ESCABOSA	74191	16.02	0.09	16.02	0.08	16.02	0.08	174
STANYAN	74269	15.36	0.01	15.34	0.02	15.34	0.02	38
CABRILLO	75066	15.43	0.02	15.39	0.02			45
DININGCAR	75095	14.72	0.18					9
OBAR	75120	15.17	0.01	15.17	0.01			25
MIZZEN	75154	15.95	0.08	15.93	0.08	15.94	0.09	148
HUSKYPUP	75297	14.46						11
KEELSON	76035	15.86	0.06	15.89	0.06	15.86	0.06	129
MIGHTYEPIC	76133	14.70	0.16					8
RUDDER	76363	15.68	0.03	15.64	0.03			72
BULKHEAD	77117	15.52	0.03	15.59	0.04	15.50	0.04	55
CREWLINE	77145	15.61	0.03	15.67	0.04			68
LOWBALL	78193	15.67	0.05	15.72	0.04	15.71	0.05	87
QUARGEL	78322	15.28	0.02	15.28	0.02			32
QUINELLA	79039	15.42	0.07	15.64	0.08			72
PYRAMID	80107	15.49	0.05	15.51	0.04	15.49	0.05	54
MINERSIRON	80305	14.72	0.01	14.79	0.01	14.91	0.01	13
BASEBALL	81015	15.90	0.05	15.88	0.07	15.87	0.05	132
JORNADO	82028	16.05	0.04	16.06	0.03	16.06	0.03	191
MOLBO	82043	16.01	0.07	16.01	0.09	15.92	0.05	138
HOSTA	82044	15.87	0.04	15.84	0.04	15.85	0.03	117
TENAJA	82107	14.32	0.01	14.29	0.01	14.32	0.01	3
GIBNE	82115	15.82	0.03	15.82	0.03	15.82	0.03	110
KRYDDOST	82126	14.04	0.01	14.05	0.01			2
BOUSCHET	82127	15.69	0.03	15.70	0.02	15.70	0.02	83
NEBBIOLO	82175	15.99	0.05	15.96	0.04	15.96	0.03	151
MONTEREY	82210	14.45	0.01	14.44	0.01	14.42	0.01	5

Table (c): Best log moments and inferred yields								
NAME	Date	M_0	σ	$M_{I(R)}$	σ	$M_{I(R+L)}$	σ	Y_{SW}
ATRISCO	82217	16.11	0.04	16.10	0.04	16.10	0.04	209
HURONLANDING	82266	14.77	0.01	14.80	0.02	14.59	0.01	10
FRISCO	82267	14.99	0.01	14.98	0.01	14.87	0.01	16
BORREGO	82272	13.98	0.01	13.96	0.01			2
MANTECA	82344	14.55	0.01	14.50	0.01	14.45	0.01	6
CABRA	83085	15.54	0.03	15.52	0.01	15.49	0.02	55
TORQUOISE	83104	15.55	0.03	15.56	0.03	15.55	0.02	59
CROWDIE	83125	14.08	0.01	14.28	0.01			3
FAHADA	83146	14.74	0.01	14.72	0.01	14.72	0.01	9
DANABLU	83160	14.47	0.01	14.48	0.01	14.48	0.01	5
CHANCELLOR	83244	15.59	0.05	15.63	0.02	15.63	0.02	71
MIDNITEZEPHYR	83264	14.21	0.01					3
TECHADO	83265	13.89	0.01	13.96	0.01	13.94	0.01	1
ROMANO	83350	15.30	0.01	15.28	0.01	15.27	0.01	31
MILAGRO	84046	14.77	0.01	14.80	0.01	14.80	0.01	10
TORTUGAS	84122	15.87	0.04	15.80	0.05	15.80	0.03	132
MUNDO	84061	15.92	0.06	15.90	0.03	15.90	0.03	105
CAPROCK	84152	15.91	0.04	15.91	0.04	15.91	0.03	135
DUORO	84172	14.82	0.01	14.70	0.01	14.70	0.01	8
KAPPELI	84207	15.56	0.07	15.68	0.02	15.69	0.02	81
CORREO	84215	14.32	0.01	14.31	0.01	14.31	0.01	3
DOLCETTO	84243	14.55	0.01	14.59	0.01	14.59	0.01	6
BRETON	84257	15.07	0.01	15.08	0.01	15.08	0.01	20
VILLITA	84315	14.10	0.01	14.15	0.01	14.20	0.01	2
EGMONT	84344	15.64	0.04	15.64	0.02	15.64	0.02	72
TIERRA	84350	15.72	0.05	15.71	0.03	15.69	0.03	85
VAUGHN	85074	14.92	0.01	14.90	0.03			14
COTTAGE	85082	15.63	0.06			15.48	0.04	50

Table (d): Best log moments and inferred yields								
NAME	Date	M_0	σ	$M_{I(R)}$	σ	$M_{I(R+L)}$	σ	Y_{SW}
HERMOSA	85092	16.10	0.08	16.12	0.10	16.12	0.07	219
MISTYRAIN	85096	15.05	0.01			14.78	0.04	19
TOWANDA	85122	15.81	0.06	15.77	0.05	15.76	0.03	96
SALUT	85163	15.91	0.05	15.92	0.04	15.93	0.03	141
SERENA	85206	15.50	0.06	15.63	0.05	15.53	0.05	71
PONIL	85270	14.71	0.01					9
ROQUEFORT	85289	14.74	0.01					9
KINIBITO	85339	15.71	0.08	15.71	0.07	15.70	0.05	83
GOLDSTONE	85362	15.67	0.05	15.63	0.04	15.65	0.04	74
GLENCOE	86081	15.50	0.02	15.46	0.04	15.35	0.02	52
MIGHTYOAK	86100	14.81	0.01	14.78	0.01	14.77	0.01	10
JEFFERSON	86112	15.68	0.06	15.78	0.04	15.78	0.03	100
PANAMINT	86141	13.97	0.11					2
TAJO	86156	15.67	0.06	15.66	0.06	15.66	0.05	76
DARWIN	86176	15.60	0.04	15.72	0.04	15.69	0.02	81
CYBAR	86198	15.84	0.07	15.83	0.05	15.83	0.04	112
CORNUCOPIA	86205	14.40	0.02					4
LABQUARK	86273	15.87	0.08	15.83	0.02	15.83	0.03	112
BELMONT	86289	15.84	0.05	15.89	0.02	15.88	0.02	126
GASCON	86318	15.91	0.04	16.00	0.09	16.00	0.07	135
BODIE	86347	15.97	0.07	15.94	0.14	15.89	0.07	155
DELAMAR	87108	15.90	0.04	15.79	0.03	15.72	0.02	87
HARDIN	87120	16.05	0.07	15.94	0.05	15.90	0.05	145
PANCHUELA	87181	14.17	0.01					2
TAHOKA	87225	16.03	0.05	16.07	0.01	16.02	0.06	195
LOCKNEY	87267	16.03	0.03	16.01	0.01	15.94	0.03	170
BORATE	87296	15.22	0.01	15.30	0.01			33